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Calibration of the J15-9 Projector at the NRL-USRD Leesburg Facility and at the NUSC Seneca Lake Facility

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A high-power underwater acoustic source for use at infrasonic and low-audio frequencies has been developed and calibrated. The source is a three-element line array projector consisting of three USRD Type J15-3 transducers electrically connected in series. It is relatively small in size, lightweight, and requires no auxiliary compensation equipment to depths of 180 meters. Calibrations at the USRD Leesburg Facility and at the NUSC Seneca Lake Facility indicate that the projector will provide a source level of 188 dB re 1 μPa from 50 to 400 Hz at a temperature of 22°C but has a lower output with decreasing temperature and increasing depth. micron

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CALIBRATION OF THE J15-9 AT THE NRL-USRD LEESBURG FACILITY AND AT THE NUSC SENECA LAKE FACILITY

INTRODUCTION

The NRL-USRD J15-9 projector (Fig. 1) is an array of three USRD type J15-3 low-audio frequency (20 to 400 Hz) transducers (Fig. 2) [1]. This array was developed to meet many requirements for a low-frequency sound source. Figure 3 shows the transmitting current response (TCR) as calibrated at the USRD Leesburg Facility at a temperature of 22°C and at a depth of 14.4 m. The TCR for one J15-3 of the array is shown as curve A, for the 3-modular array connected in series as curve B, and for the maximum source level attainable from the J15-9 as curve C. The array is capable of reproducing nine different frequencies simultaneously at an output comparable to the maximum cw output of each single driver assembly and will operate to a depth of 180 m with no external air supply. Other sources which compare to the J15-9 are usually larger in size and weight and their operational bandwidths are not as wide.

While the J15-3 transducer in the array is a well-tested standard cw source [2], the J15-9 has been subjected to a minimum of testing. It was known from previous calibrations of the J15-3 transducer that the J15-9 source response would change with operating depth and decreasing water temperature, but the extent of the changes could be determined only by calibrating it under specific environmental conditions. NUSC's Seneca Lake Facility offered these environments--the temperature of the lake in December is 4.4°C with no thermocline, and calibration depths of 152 m are available.

DISCUSSION

Each driving element of the J15-9 array is an electrodynamically driven piston 10 cm in diameter and is identical to the driver assembly for the USRD J13 transducer (Fig. 4) [3]. The rigid piston is driven by a force produced by a moving coil in a magnetic field. The one piece piston and coil form carries 212 turns of A.W.G. #30 copper wire, and the piston is suspended from a convoluted neoprene circumferential seal. The development of this seal, and the Type W Neoprene material it is made of, has been an important factor in the success of the driver assembly. This seal serves as the restoring force for the piston and

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must withstand the heated oil which fills the transducer. The piston is centered in the gap of the magnet by a center guide pin and Teflon bushing assembly; front and rear mechanical stops prevent the piston from exceeding its maximum allowable displacement. The magnetic flux in the gap provided for the coil is produced by a 3.6-kg ALNICO V-7 magnet with the magnetic path formed by three copper-plated magnet iron pole pieces. The magnet gap and front cavity are filled with castor oil, which acts as a coupling medium to the water through a neoprene acoustic window which also provides a watertight seal for the oil-filled cavity. The maximum acoustic output of the single driver element is limited by the maximum allowable electrical input to the coil at the higher frequencies and the maximum allowable displacement of the piston at low frequencies. Above the frequency at which the output is limited by piston displacement, the maximum power input is determined by the rate at which heat generated in the driving coil can be dissipated, which was determined to be a nominal 250 watts at a driving current of 3A. Several methods for faster dissipation of the heat are being tested--one is exposing the piston cone directly to the water. An experimental model utilizing the exposed cone technique is now under test at the USRD's Leesburg Facility. If this method proves successful, the driving level can be increased to 5 A at frequencies above 100 Hz. The maximum piston peak-to-peak displacement of the present design is 12 mm which limits the output at frequencies below 100 Hz.

A single J15-3 transducer in the J15-9 is made up of 3 of the electrodynamic driver elements. Each driver can be connected electrically in series or parallel at the top end of the 6-conductor electrical cable. When connected in series, the coils of all three pistons are subjected to the same current; therefore, the output is increased by 20 log 3, or 9.5 dB. With this arrangement the three individual impedances will add together. The disadvantage of connecting the coils in parallel is that each driver assembly could be subjected to different currents if the impedances are slightly different; therefore, the outputs will be unequal. For this reason, parallel connection is not recommended. Each of the three pistons can also be driven individually with different frequencies and driving levels, allowing several frequencies to be produced in the water at the same time. Each piston can be driven simultaneously at two frequencies as long as one driving frequency is at least 10 dB lower than the other. That is, the basic J15-3 can apply six different frequencies to a test medium simultaneously. The J15-3 can also be driven with noise, as long as a clipping network is used to keep the voltage spikes from exceeding the maximum input levels. The transducer is pressure compensated to a depth of 240 m by a self-contained, passive-air-bag system (Fig. 2). The elastic bag is made of a butyl rubber compound whose permeability to water and air is very low. As the operating depth increases, the bag is compressed by the water pressure which increases the air pressure behind the piston to compensate for the higher hydrostatic pressure.

The resonance frequency of the driver assembly increases as the operating depth is increased due to the high stiffness of the air behind the diaphragm. This can limit the depth to which the transducer may be lowered if high output is required at the lower frequencies.

CONSTRUCTION OF THE ARRAY

The J15-9 array consists of three J15-3 transducers in a vertical line (Fig. 1). The line array framework is made of free-flooding aluminum tubing designed to facilitate quick assembly or removal of the three J15-3 transducers. The individual frame members are made symmetrical to simplify assembly. Mechanical isolation of each J15-3 is provided by rubber shock mounts separating each transducer from the framework at three mounting points. The vertical distance between each transducer was determined by mounting them close enough together to keep the overall array dimensions small, compared to a wavelength, and yet far enough apart so that the volume velocity of each J15-3 would not be adversely affected.

Electrical connections to the J15-9 consist of three 6-conductor, MCOS-6 cables each terminated at a J15-3 by a 6-pin Marsh Marine underwater connector. The mating 6-pin connectors, protruding from each bulkhead, electrically connect the wires to each of the driving assembly coils (Fig. 5).

Various driving configurations can be achieved at the surface, without removing the J15-9 from the water. Each diaphragm can be driven at a different frequency with a maximum output comparable to a J13 assembly for a total of nine frequencies in the water at one time. A combination of three modules, each connected in series, gives three frequencies in the water at the same time with a maximum output of a J15-3 transducer. All nine modules connected in series in the configuration shown in Fig. 5 yield the maximum output of the J15-9. If any individual element fails, it can be disconnected from the circuit and the test will not be interrupted. The modular construction of both the J15-9 and the J15-3 permits the replacement of an entire J15-3 transducer or the replacement of any individual driver element.

TEST PROCEDURE

The J15-9 was calibrated at the USRD Leesburg Facility and at the NUSC Seneca Lake Facility. In order to establish some criteria for comparison of data from the two facilities, a monitor hydrophone was mounted on the J15-9 (Fig. 6) and a test depth common to both facilities was established. The monitor hydrophone was a USRD type F37. It was arbitrarily mounted 73 cm from the acoustic center of the J15-9 and suspended by bungy cord for acoustic isolation. Calibration curves

from both the Leesburg Facility and the Lake Seneca Facility show comparison of the F37 mounted to the J15-9 to a standard hydrophone in the far field. This calibration information with the F37 mounted to the projector is necessary if the J15-9 is used at sea in measurements where a monitor phone is required. This distance correction 20 log 73/100 which corrects the TCR to 1 m has been applied to all calibration curves.

A test depth common to both the Leesburg Facility and the Seneca Lake Facility is 14.4 m; however, due to rigging problems, Seneca Lake measurements were made at 18.3 m. At this shallow depth, 4 m does not present a noticeable change in response of the J15-9.

CALIBRATION DATA

Figure 7 shows the TCR of the J15-9 at 1 m taken at the USRD Leesburg Facility with the calibration depth at 14.4 and the water temperature at 22°C. Curve A is the TCR from a USRD standard hydrophone in the far field. Curve B is the TCR from a type F37 mounted to the J15-9 and acoustically isolated from the projector. The fact that curve B is lower and does not coincide with curve A clearly indicates that the F37 mounted to the J15-9 is <u>not</u> in the far field. An average correction of from 2 dB to 3 dB, depending on the frequency, is necessary if this monitor hydrophone arrangement is used on the at-sea tests of the J15-9 as a true measure of the source level. However, it does provide a reference for any changes in sound pressure during the measurement. The resonance in curve B at 28 Hz is caused by the isolation material which isolates and mounts the monitoring transducer.

Figure 8 shows the TCR of the J15-9 at 1 m at the Seneca Lake Facility. The calibration depth is 18.3 m and the water temperature is 4.4°C. Except for temperature this calibration simulates the Leesburg calibration shown in Fig. 6. The amplitude of the resonance at 28 Hz has increased due to the decrease in the effectiveness of the isolating material at 4.4°C.

Figure 9 shows the TCR of the J15-9 at 1 m comparing the Leesburg Facility TCR (curve B of Fig. 7) to Seneca Lake TCR (curve B of Fig. 8). This figure presents two parameters which were the same when measurements were made at the Leesburg and Seneca Lake Facilities--essentially the same hydrostatic pressure and the same monitor hydrophone. The parameter that was different was the water temperature.

Figure 10 shows the TCR of the J15-9 at 1 m when at the Seneca Lake Facility. The calibration depth is 61 m and the water temperature is 4.4°C. A decrease in output is observed due to an increase in hydrostatic pressure. The decrease varies with frequency but is more pronounced below 100 Hz. A comparison of the TCR's with varying depths

vs. constant temperature is shown in Fig. 15. Curve C is plotted from data taken point-by-point. Since surface and bottom reflections presented a problem in the far field, the F37 mounted to the J15-9 was used as the receiver. The J15-9 was driven with 750 MA at 1000 Hz for 5 minutes in order to raise the temperature of tne projector elements prior to taking these measurements.

In Fig. 11 the maximum output response is shown below 40 Hz at 61-m depth and at a water temperature of 4.4°C. Curve A shows the TCR. Since the driver assemblies are displacement limited below 80 Hz, curve B is the maximum source level output of the J15-9 with the current reduced to less than 1 A to prevent the diaphragm from hitting the stops. The F37 mounted to the projector was used to monitor the output.

Figure 12 shows varying drive levels at a constant depth of 61 m and at a water temperature of 4.4°C. Curve A is the projector output response when driving the projector with 1 A, curve B when driving with 1.8 A, and curve C when driving with 2.9 A. Due to displacement limitations of the J15-9 module pistons at the lower frequencies, curve C measurement was stopped at 80 Hz. At this temperature and depth the source level is lower than that normally measured at a depth of 14 to 16 m and a water temperature of 22°C. There are some inconsistencies in this data which could be resolved only by making additional measurements at the Seneca Lake Facility.

Figure 13 shows the TCR at 76.2-m depth and the water temperature at 4.4°C. A further decrease in the output response is observed as a result of increase in hydrostatic pressure. Curve A is shown in the family of curves comparing output responses with varying depths at a constant temperature. Data for curve C were measured point-by-point and were taken 20 days later on a different calibration barge at Seneca Lake. Curves A and B were not available for comparison when curve C was taken because the author had carried it to the USRD. The cause of the 3-dB difference has not been determined.

Figure 14 is the sound-pressure level at 1 m with varying drive levels at a constant depth of 114 m. Curve A is with 1 A driving the J15-9, curve B is with 1.8 A driving, and curve C is with 3 A driving. The measurement hydrophone was a type H56 mounted in the far field. Due to the increase in hydrostatic pressure and cold water, the output levels measured are lower. Curve D (from Fig. 3 curve C) is the sound-pressure level measured at the Leesburg Facility at 22°C and 14.4-m depth with a driving current of 3A.

Figure 15 shows the TCR at 1 m with varying depths at a constant temperature of 4.4°C. Curve A was measured at 18.3-m depth, curve B at 61 m, and curve C at 114 m.

CONCLUSION

A calibration of the J15-3 to depths of 152 m at sea showed less reduction in response with depth above 150 Hz. The reduction in response with depth below 150 Hz was close to that shown in the Seneca Lake calibration. This change in response with depth should be similar for the J15-9. It is possible that the J15-9 was not fully pressure compensated during the calibration at Seneca Lake at 114-m depth due to insufficient air in the compensation bags at 4.4°C.

The J15-9 projector meets and exceeds many low-frequency sound-source requirements. The projector will provide a source level of 189 dB re 1 μPa from 50 to 400 Hz in warm water, will operate at reduced levels from 10 to 50 Hz, will operate to depths of 150 m with no external air for compensation, can put as many as 18 signals and noise bands into the water at one time, weighs only 108 kg in water, and costs less than $50,000 to construct. The projector's present design allows the TCR to be affected by cold water and hydrostatic pressure. However, with improvements being planned, such as a silicone oil or polyalkylene gylcol fluid replacing the castor oil and the exposed cone design to dissipate heat faster and thus allow higher drive levels, these deficiencies will be lessened.

ACKNOWLEDGEMENTS

Mark Young and Dick Hugus of the USRD designed the J15-9 framework and supervised testing of the transducer at the Leesburg Facility. Allan Tims of the USRD assisted the author in the assembly and calibrations at Seneca Lake in sub-zero temperatures. Without the special assistance and cooperation of Joe Navin, Gordon Hanson, and the NUSC Seneca Lake personnel, the cold-water calibrations would not have been possible at this time.

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[1] A. Mark Young, "Proposal for the Development of a High-Power, Low Frequency Underwater Acoustic Source," NRL Memorandum Report 2897, 1 Nov 1974.

[2] I. D. Groves, "Twenty Years of Underwater Electroacoustic Standards," NRL Report 7735, 21 Feb 1974, pp. 120-131.

[3] A. Mark Young, "An Underwater Acoustic Source for the Infrasonic and Low-Audio Frequency Range (USRD Type J13 Transducer)," NRL Report 7967, 30 Dec 1975.

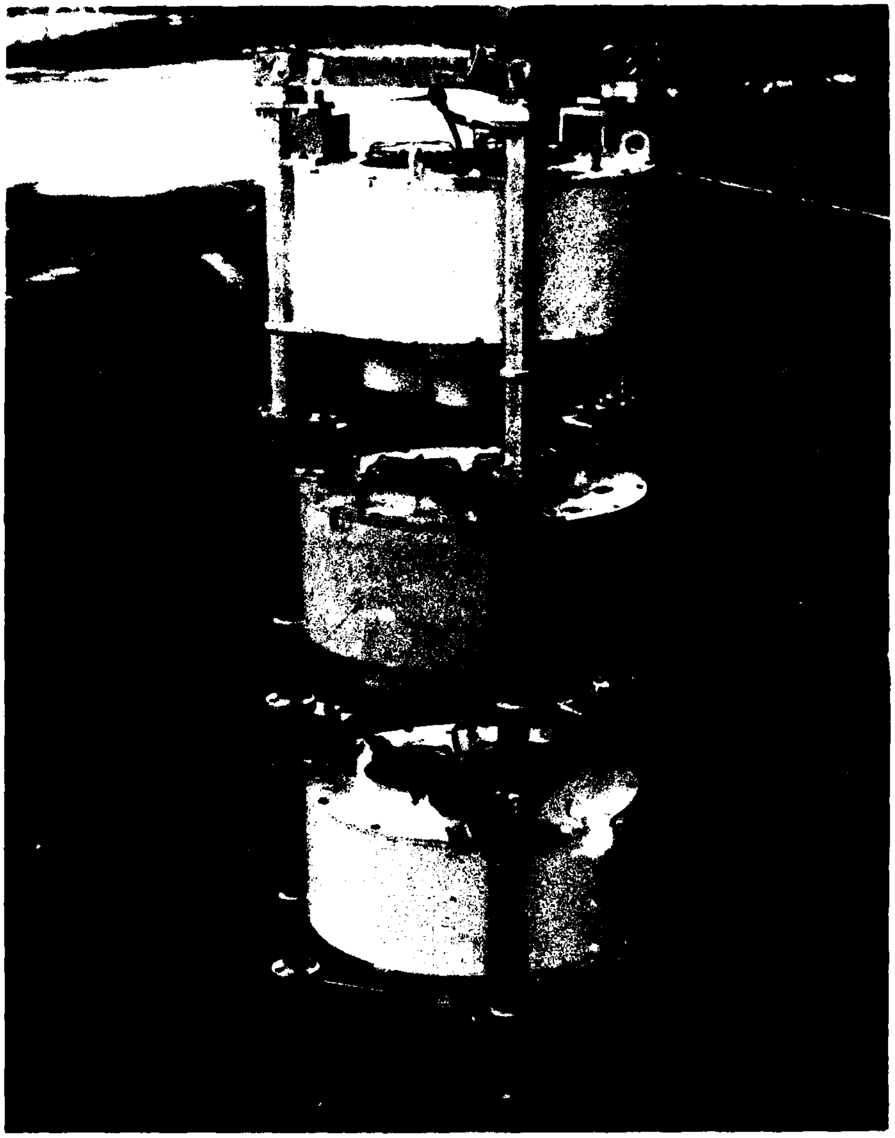


Fig. 1 — NRL-USRD J15-9 Projector

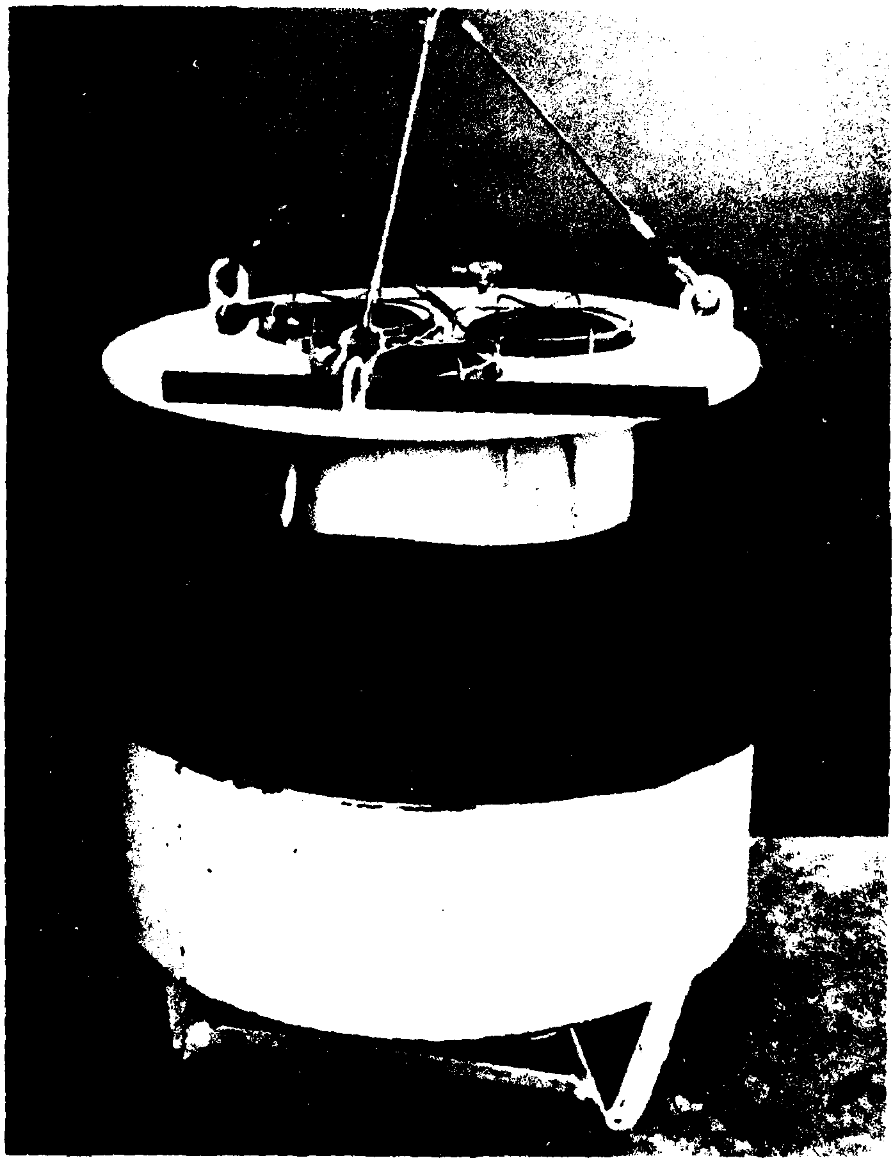


Fig. 2 — USRD J15-3 projector exposing the compensation bag

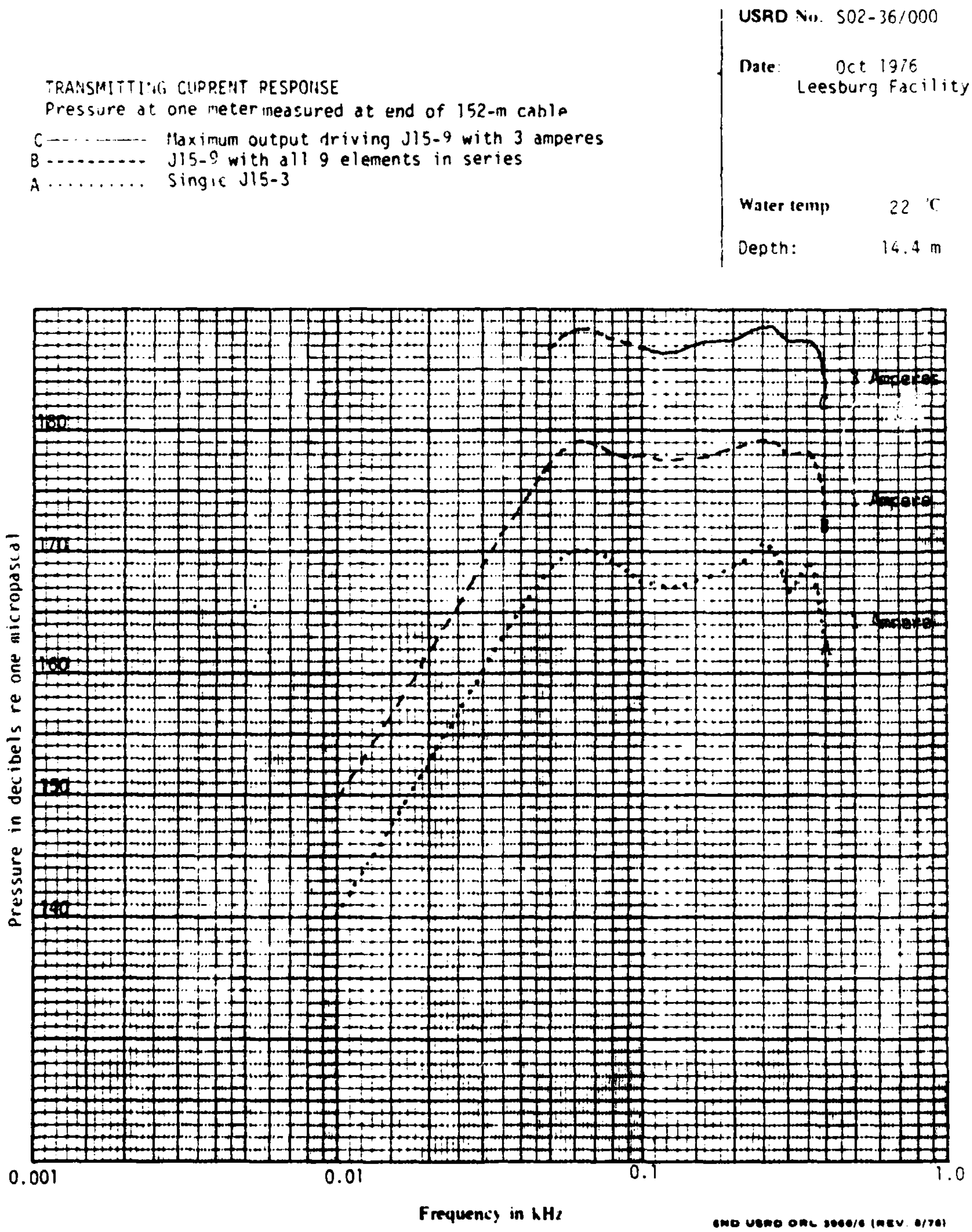


Fig. 3 — USRD Leesburg calibration of J15-9 projector

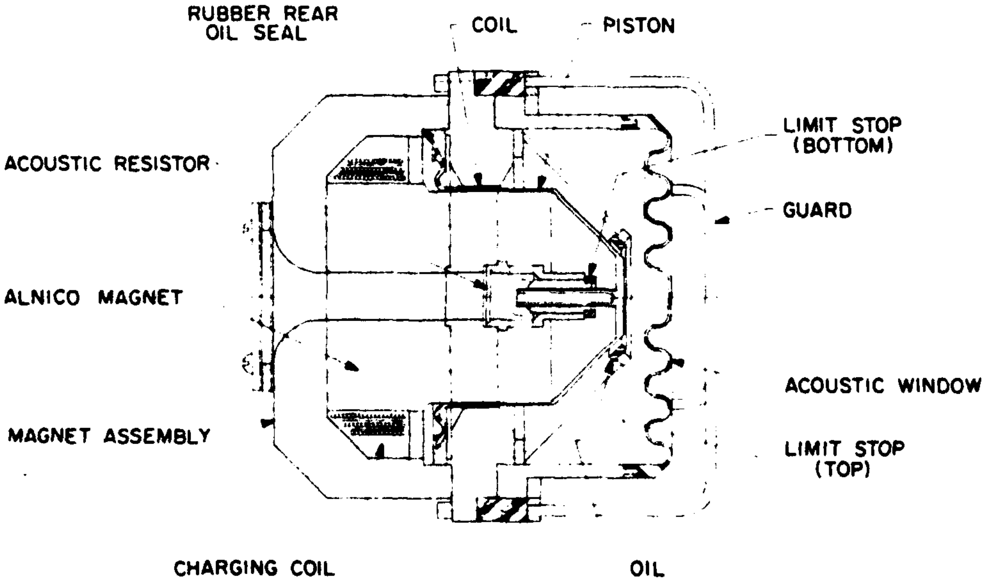


Fig. 4 — Single driving element of the J15-9

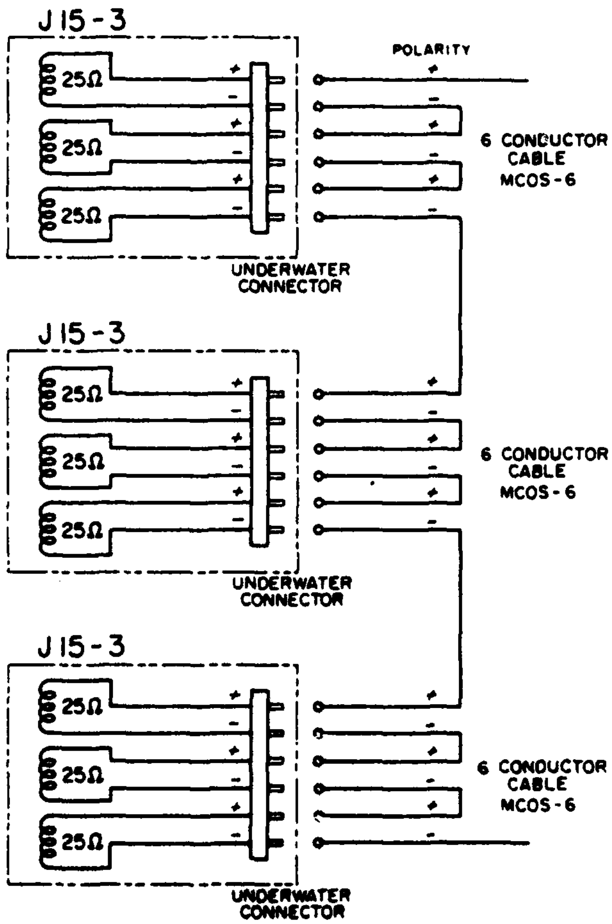


Fig. 5 — Wiring diagram for J15-9 in series connection

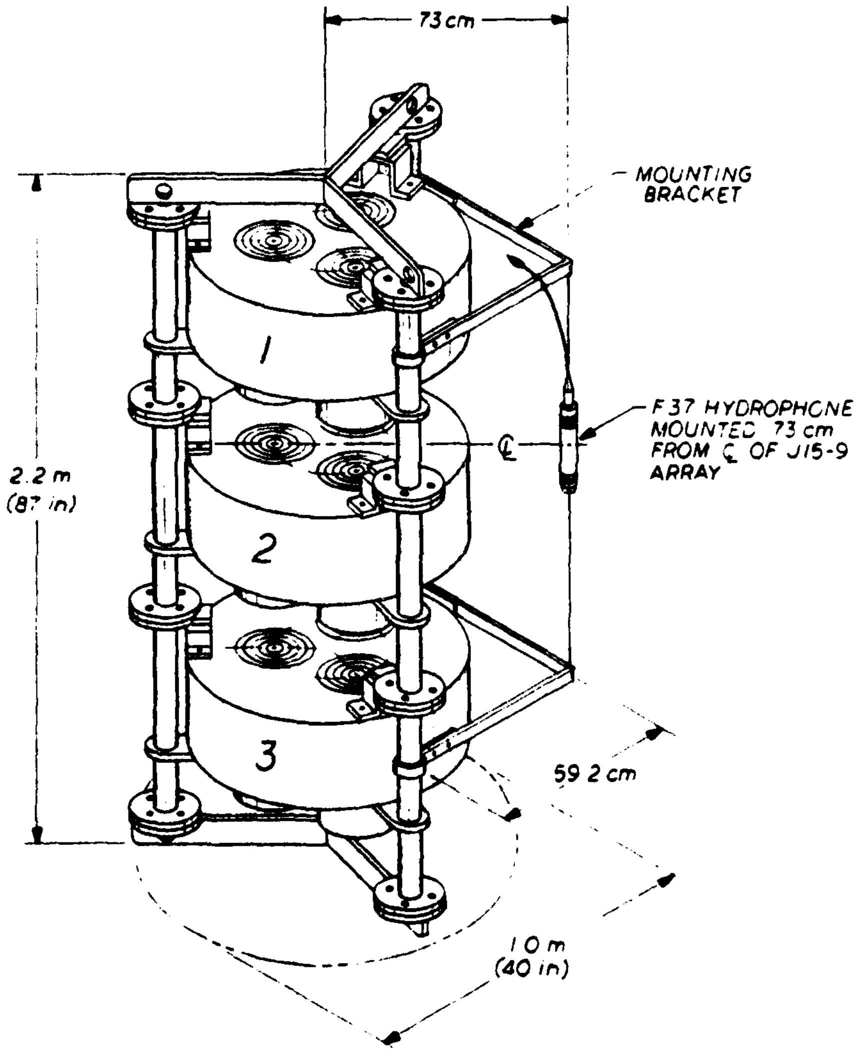


Fig. 6 — J15-9 showing framework arrangement and monitor hydrophone mounting

TRANSMITTING CURRENT RESPONSE
Pressure at one meter per ampere

A ‒ ‒ ‒ ‒ Free field
B ---------- F37, A69 mounted on J15-9

USRD No. S02-36/000

Date: Nov 1976
Leesburg Facility

Water temp. 22 °C

Depth: 14.4 m

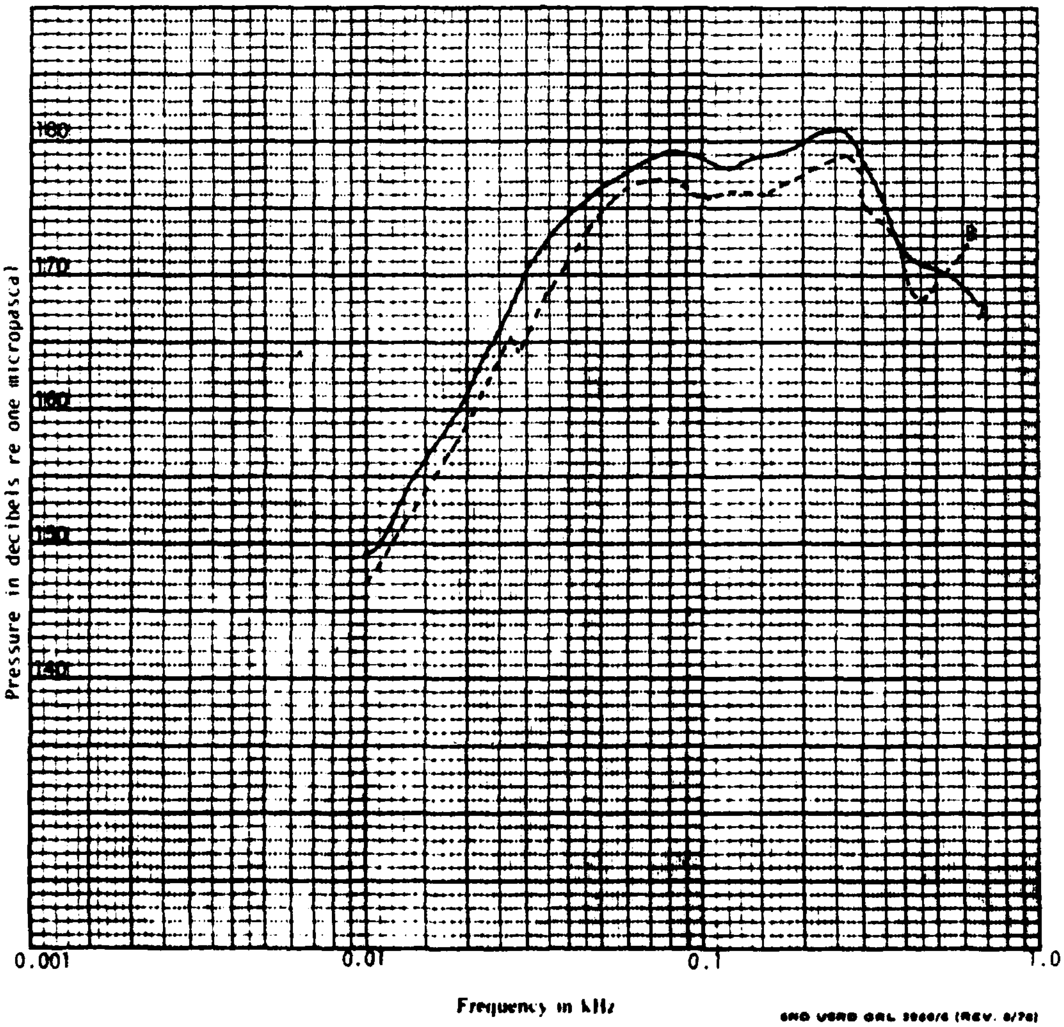


Fig. 7 — TCR, J15-9 Leesburg Facility

USRD No. S02-36/000

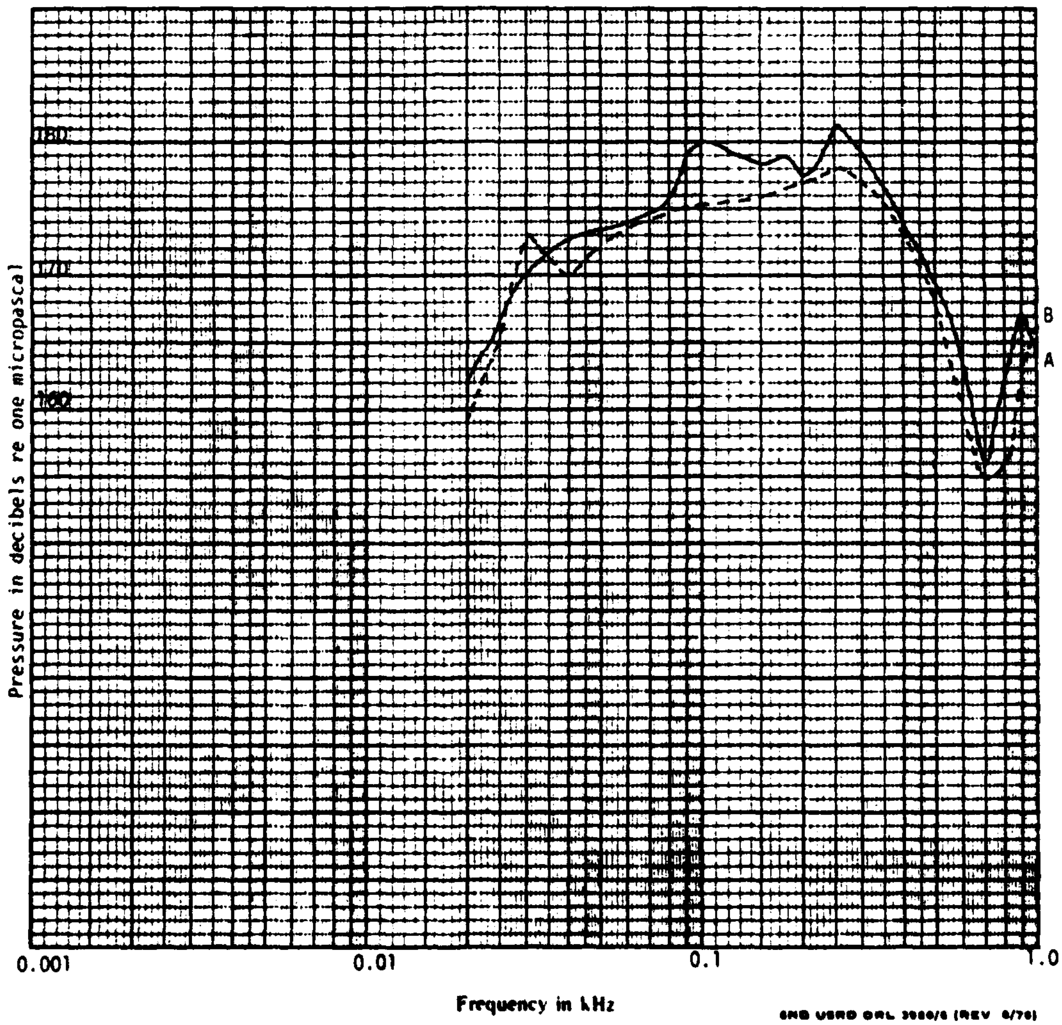
Date: 1 Dec 1976
Seneca Lake Facility

TRANSMITTING CURRENT RESPONSE
Pressure at one meter per ampere

———— A - H56 in free field
---------- B - F37 mounted to the J15-9

Water temp. 4.4 °C

Depth: 18.3 m



NRB USRD ORL 3060/6 (REV 6/76)

Fig. 8 — TCR, Seneca Lake Facility, 18.3-m depth

USRD No. S02-36/000

Date 20 Dec 1976
Seneca Lake Facility
and Leesburg Facility

TRANSMITTING CURRENT RESPONSE
Pressure at one meter **per ampere**

A ———— Calibration at Leesburg Facility 14.4 depth, 22°C
Receiver - F37 mounted to J15-9

B - - - - - Calibration at Seneca Lake Facility 18.3 m depth, 4.4°C
Receiver - F37 mounted to J15-9

Water temp. A - 22°C
B - 4.4°C

Depth: A - 14.4 m
B - 18.3 m

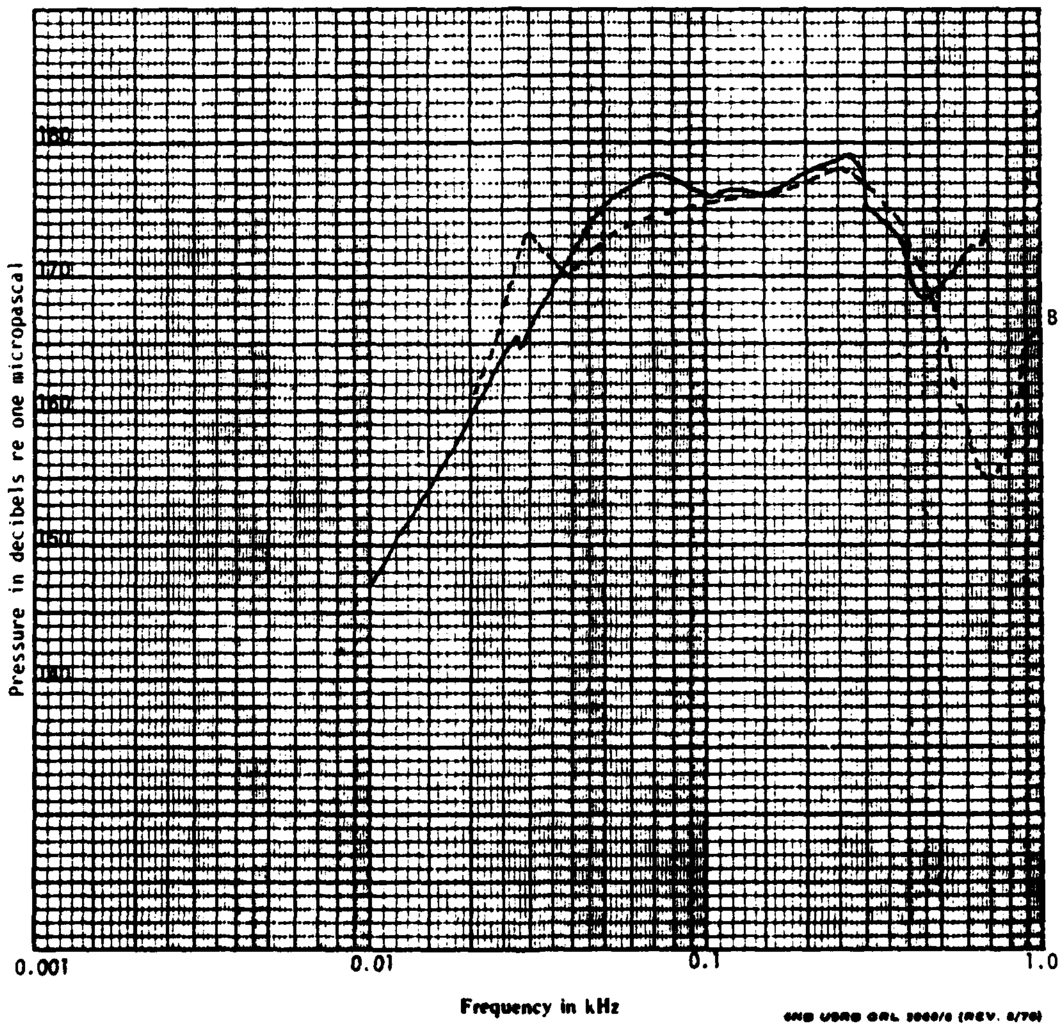


Fig. 9 — Compare TCR of Seneca Lake and Leesburg Facilities, constant depth

USRD No. S02-36/000

Date: 20 Dec 1976
Seneca Lake Facility

TRANSMITTING CURRENT REPONSE
Pressure at one meter per ampere

———— A - Receiver is H56 hydrophone in far field
--------- B - F37 transducer mounted to the J15-9
.... C - F37 transducer in the near field 71 cm dist.
The J15-9 was driven at 750 ma at 1000 Hz for
5 minutes prior to this measurement.

Water temp. 4.4 °C

Depth: 61 m

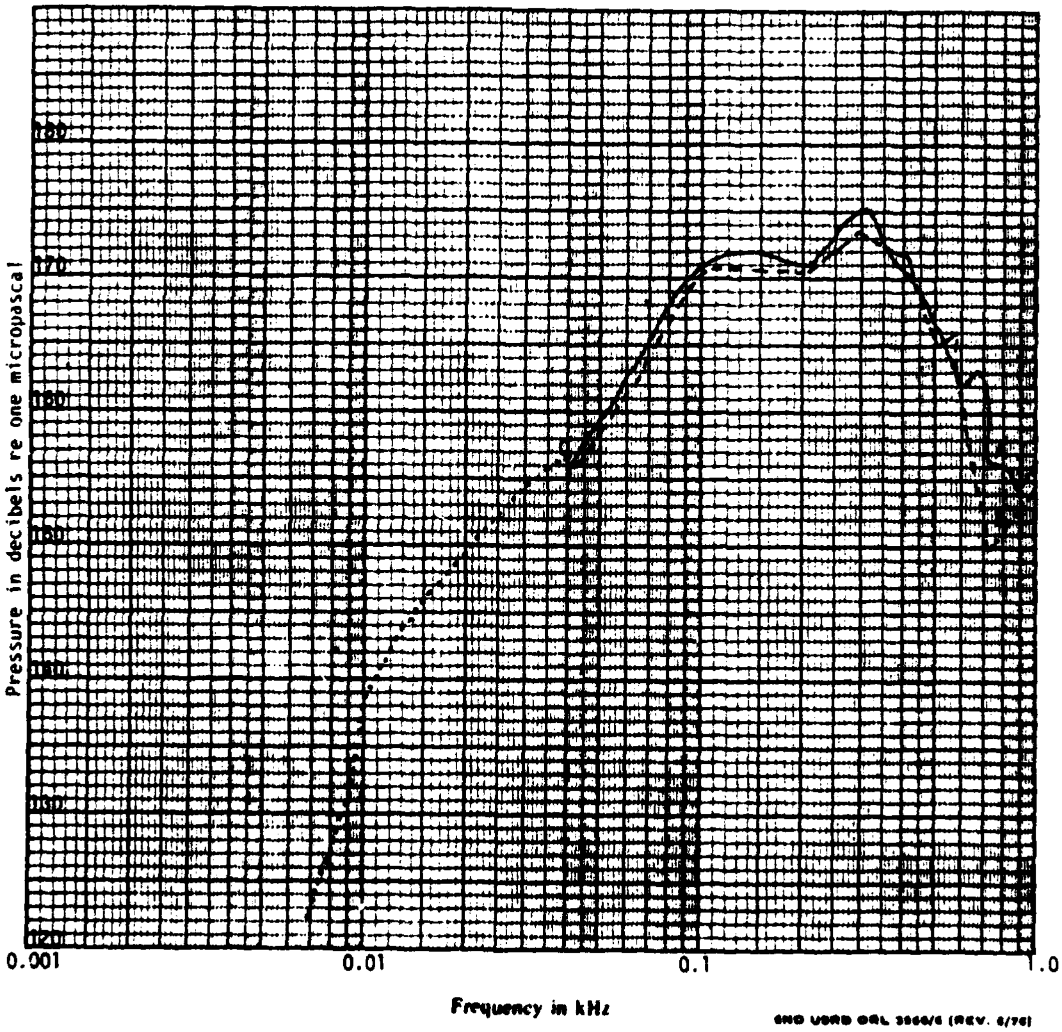


Fig. 10 — TCR, Seneca Lake Facility, 61-m depth

USRD No. S02-36/000

Date 20 Dec 1976
Seneca Lake Facility

TRANSMITTING CURRENT RESPONSE
———— A - SPL in dB re one ampere at one meter
---------- B - Maximum source level drive

Water temp. 4.4 °C
Depth: 61 m

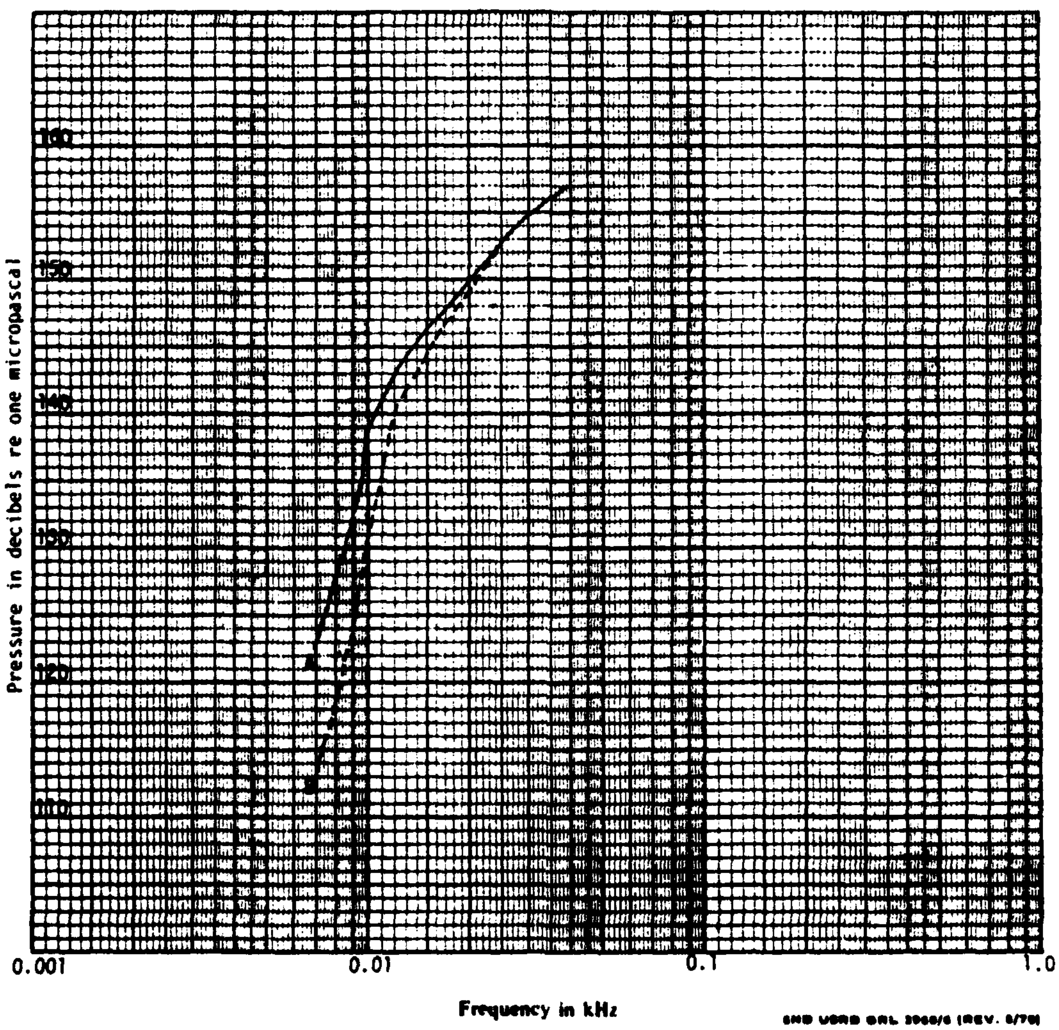


Fig. 11 — TCR, Seneca Lake Facility, 61-m depth, 7-40 Hz

USRD No. S02-36/000

Date 20 Dec 1976
Seneca Lake Facility

SOUND PRESSURE LEVEL AT ONE METER
———— A - 1.0 ampere driving
- - - - - B - 1.8 ampere driving
.... C - 2.9 ampere driving
Receiver H56 is in the far field

Water temp 4.4 °C
Depth: 61 m

Constant depth and temp - varying drive levels

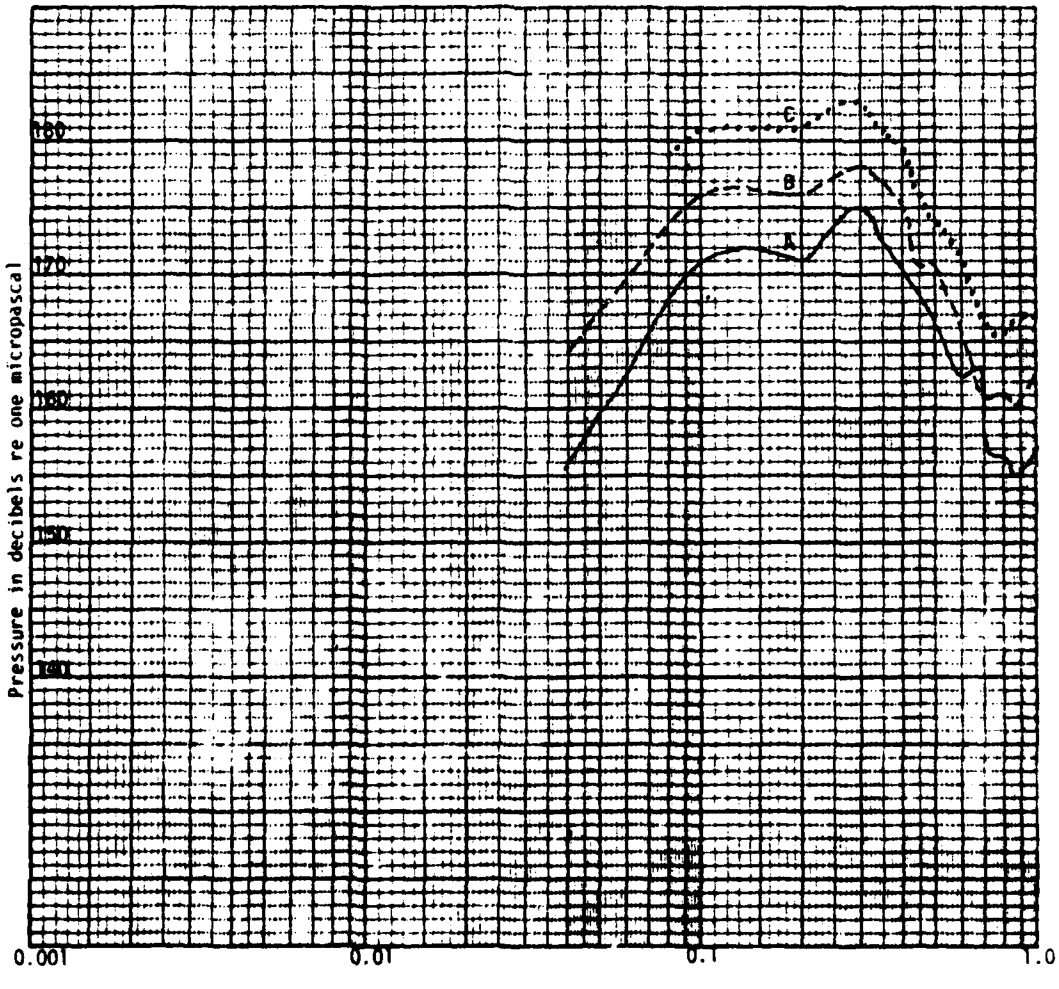


Fig. 12 — SPL, Seneca Lake Facility, 61-m depth, constant depth and temperature-varying drive levels

USRD No. S02-36/000

Date: 1 Dec 1976
Seneca Lake Facility

Water temp. 4.4 °C

Depth: 76.2 m

TRANSMITTING CURRENT RESPONSE
Pressure at one meter per ampere

—————— A - H56 in free field
---------- B - F37 mounted to J15-9
.... C - F37 mounted to J15-9m

Fig. 13 — TCR, Seneca Lake Facility, 76.2-m depth

USRD No. S02-36/000

Date: 1 Dec 1976
Seneca Lake Facility

SOUND PRESSURE LEVEL AT ONE METER

-·-·-·- A - 1.0 ampere driving
-------- B - 1.8 ampere driving
.... C - 3.0 ampere driving
-.-.-.-. D - 3.0 ampere 22°C water temp., 14.4-m depth
Receiver H56 is in the far field

Constant depth and temperature - varying drove levels
compared with Leesburg calibration

Water temp 4.4 °C

Depth: 114.0 m

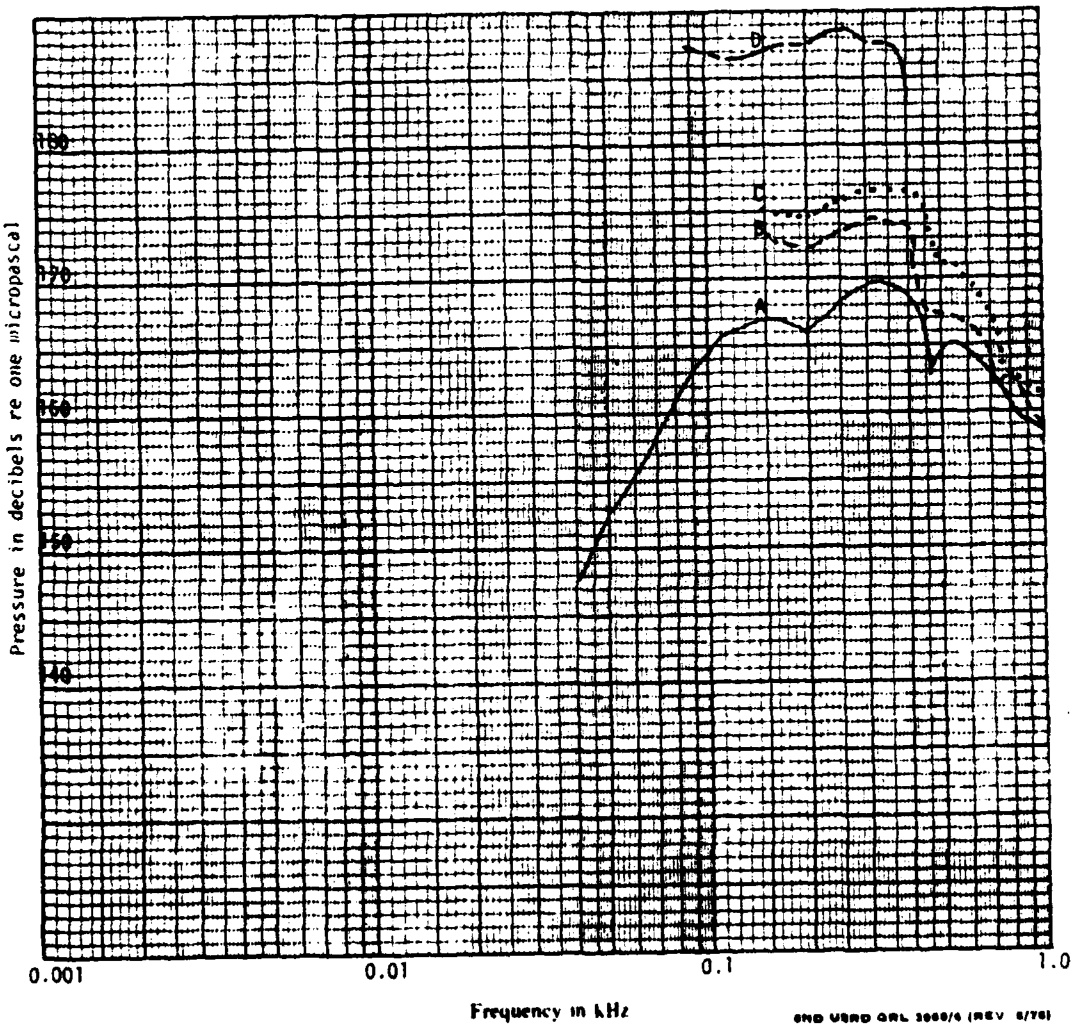


Fig. 14 — SPL, Seneca Lake Facility, 114-m depth, constant depth and temperature-varying drive levels

USRD No. S02-36/000

Date 20 Dec 1976
Seneca Lake Facility

TRANSMITTING CURRENT RESPONSE
Pressure at one meter per ampere

———— A - 18.3 m depth
-------- B - 61.0 m depth
.... C - 114.0 m depth

Varying depths - constant temperature

Water temp 4.4 °C

Hydrostatic Pressure As noted

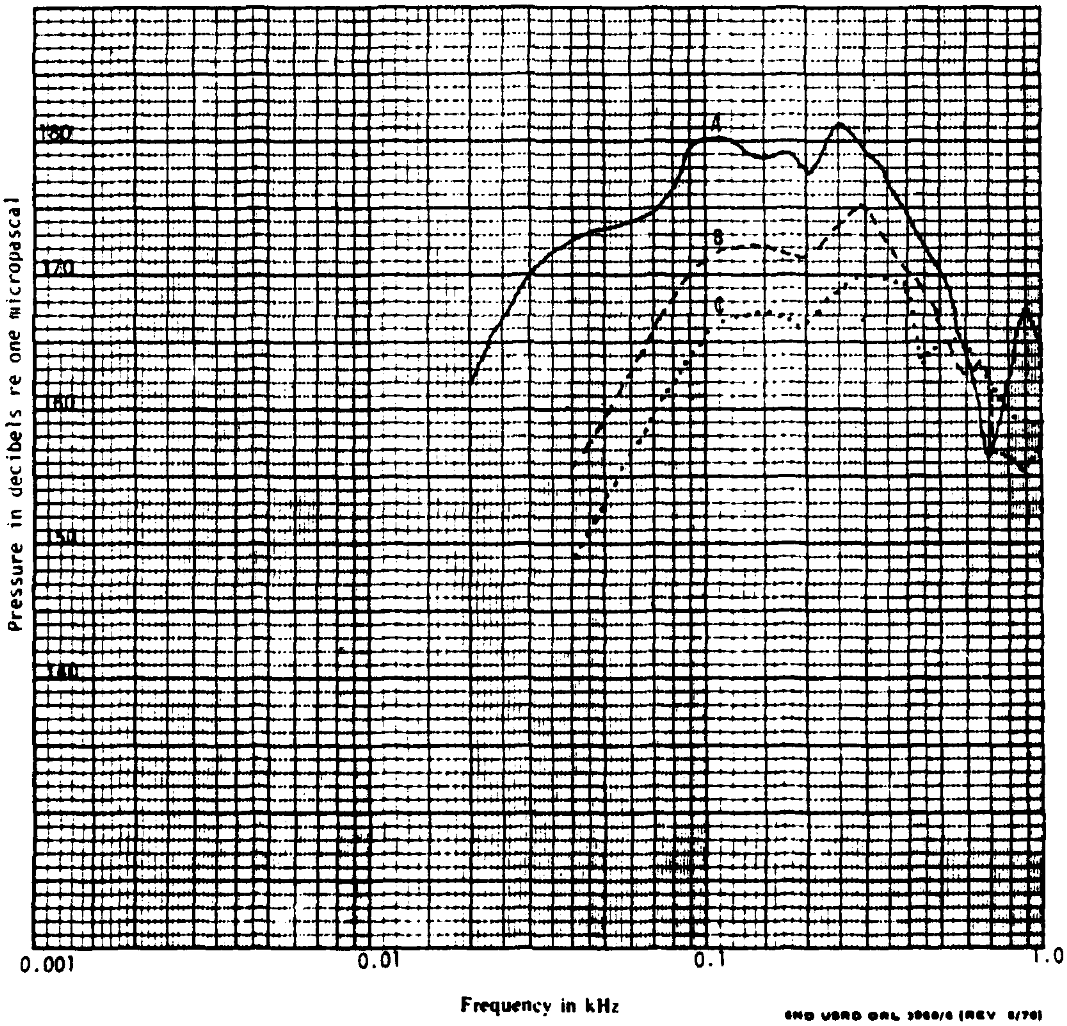


Fig. 15 — TCR, Seneca Lake Facility, varying depths - constant temperature